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# URBAN INFRASTRUCTUR E RESEARCH PLAN

## WATER AND WASTEWATER ISSUES

### INTRODUCTION

As we approach the twenty-first century, we should be considering where we are today and where the consequences of our actions will place us tomorrow. This is especially true in the management of our aging and growing infrastructure. Infrastructure facilitates movement of people and goods, provides adequate safe water for drinking and other uses, provides energy where it is needed, removes wastes, and generally supports our economy and quality of life. The demand for infrastructure worldwide is huge, approximating $3 trillion annually.[1] Many areas of the world are currently experiencing rapid growth, with the associated need for their infrastructure to support that growth. At the same time, developed areas are replacing old and obsolete infrastructures to meet existing and future requirements. Besides the need to address the immediate problems associated with infrastructure, there is a need to make fundamental changes in the way infrastructure is designed, built, utilized, maintained and renewed if we are to achieve economic growth while preserving and enhancing environmental quality.

In 1988, the National Council on Public Works Improvement, aCongressionally mandated special commission, issued a report on the state of this country's infrastructure. The Commission looked at eight infrastructure areas: highways, mass transit, aviation, water resources, water supply, wastewater, solid waste, and hazardous waste. Based on the Council's findings, it is estimated that this nation would have to invest over $100 billion each year in new and existing public works. Obviously, a tremendous effort must be put forth to ensure that these resources are spent on cost-effective, technologically sound remedies that will meet national environmental goals.[2]

A 1990 report by the Congressional Office of Technology Assessment identified environmental infrastructure problems in the areas of wastewater, drinking water and municipal solid waste and evaluated the impacts of these problems on local communities. As is apparent, a community's environmental infrastructure needs are varied and interrelated. Communities may have the same generic needs (providing safe drinking water, protecting receiving waters, environmentally acceptable disposal of solid waste, etc.) and associated problems, however, the solutions to these problems can vary greatly with community size because smaller communities generally lack the financial (lower per-capita income, smaller tax base, etc.) and personnel resources (operation, maintenance, management, etc.) of larger ones, forcing the use of lower-cost, less-complex technologies.[3]

A community's first step to providing quality environmental services is to identify and characterize its environmental infrastructure components. In 1994, the American Society of Civil Engineers' (ASCE) Civil Engineering Research Foundation conducted a survey of approximately 800 municipalities, nationwide. The purpose of the survey was to evaluate infrastructure conditions and the most critical and frequent problems and needs for seven infrastructure systems: buildings, transportation, solid waste, hazardous waste, power & energy, wastewater, and water resources. The results of the survey were analyzed and prioritized resulting in a list of specific problems and needs, many identified as not being adequately addressed by current research (Table 1).[4] Appendix A provides a brief discussion of select national priority items in Table 1 that relate to EPA's National Risk Management Research Laboratory (NRMRL) activities (asterisked items).

This research plan will address many of the above nationally-identified priority infrastructure issues, as they relate to the mission of NRMRL's Water Supply and Water Resources Division (WSWRD). It presents a focused approach, for water and wastewater issues, emphasizing "retrospective" activities associated with aging and obsolete infrastructures and "prospective" activities associated with the development of sustainable technologies forfuture growth considering the preservation and enhancement of environmental quality. Near-term research activities could be initiated at NRMRL's existing multi-million dollar Urban Watershed Research Facility (UWRF), located in Edison, NJ; Appendix B provides a brief description of the facility. This facility is currently undergoing extensive modification, including the upgrading of experimental conveyance and storage systems. The enhanced facility will be capable of supporting controlled-condition experiments on simulated urban infrastructure problems; principally, those problems associated with water supply and wastewater issues. These problems and issues are addressed in this plan within the context of the following categories:

**A. CONVEYANCE SYSTEMS**

A.1 Potable Water
A.2 Petroleum and Chemical
A.3 Stormwater and Wastewater
A.4 Hot and Chilled Water and Steam

**B. STORAGE SYSTEMS**

B.1 Potable Water
B.2 Petroleum and Chemical
B.3 Stormwater and Wastewater

**C. SUSTAINABLE TECHNOLOGY DEVELOPMENT**

C.1 Community-Based Issues
C.2 Decision Support Tools

## A.1 CONVEYANCE SYSTEMS: POTABLE WATER

Not surprisingly, there is a greater and more tangible urgency in water supply and distribution then any other area of infrastructure. Of the approximately 200,000 public water systems in the United States, about 30% are community water systems which serve primarily residential areas and 90% of the population. Potable water conveyance within these 60,000 community systems represents an estimated 850,000 miles of pipe. Much of this pipe has been installed since World War II, is less than 30 years old and is judged to be in good condition. However, 26% of this piping is unlined cast iron and steel and is judged to be in fair or poor condition at best from a structural and hydraulic viewpoint; requiring accelerated repair and replacement.[5]

Water distribution systems represent a major capital investment; utilities must ensure they are getting the highest yield possible on that investment, both in terms of dollars and water quality. Knowing when pipe failure is likely to occur, and being able to detect and locate failures quickly and accurately gives utilities leverage on cost-effective planning and management of infrastructure needs on a system-wide basis.

Most of the Federal regulations have focused on water treatment even though it is well known that the delivery system itself can cause significant deterioration of water quality. For example, many mechanisms can introduce bacteria into drinking water during distribution. These include open reservoirs, enclosed reservoirs to which chlorine is not added, new construction that may disturb the existing distribution system, main breaks (an increasing problem in aging systems), back pressure, dead ends in mains that stagnate water, and living organisms that protect bacteria but may release bacteria into the drinking water when mains are disturbed. In addition to bacterial contamination, corrosion by-products can also cause deterioration of water quality.[6]

There are many important interactions between water quality and cost. For example, long-term corrosion of older mains can result in tuberculation, thereby reducing the pipe's carrying capacity. The reduction in carrying capacity requires increasing investments in power and pumping, causing a trade-off between the reduction in hydraulic capacity and the increased operation and maintenance costs to get water from one point to another. Also, bacterial growth within tubercles may cause a potential health problem. Tuberculation also weakens the main by reducing the wall thickness. These reductions in carrying capacity and in strength can increase pumping, breakage, and repair costs, and, consequently, the cost of water delivery.

Water supply is also an important economic good. Capital investment in water supply has averaged $3.3 billion a year for the last five years, and annual operating and maintenance expenses amount to a total of approximately $3 billion each year. Transmission and distribution account for the largest percentage of capital investment, and represents a significant portion of the operating cost investment.[6] In 1994 alone, the U.S. Army spent $37 million or $3000/mile to maintain their water distribution piping; total cost for service was $82 million.[7] The distribution system often involves as much as 80 percent of the total expenditure in drinking water systems.[6]

**Research Problem**

Piping materials used for transmission of potable water include: ductile and cast iron, metallic piping such as steel and copper,and more recently plastic (polyethylene). Over time the integrity of these lines and their joints fail, whether due to pressure surges, disturbance by construction or direct tapping, natural disturbance by expansive soil, frost penetration, tree roots, or seismic activity.

Observance of loss of pressure and an unintended water spout are obvious signs of a leak in a pressurized pipe. Detecting not so obvious problems in a transmission line is not that simple and smoke test methods frequently cannot locate small leaks. Remote videotaping of a collection line, use of radar or other advanced means of "reading" a pipe's condition underground, and physical inspection of a line in the area of a suspected problem are not always possible and can be unsafe, costly in manpower hours, disruptive, politically insensitive, and/or incur significant replacement costs. Infiltration/inflow-analysis (flow tests),relatively simple when input data is available, becomes problematic when input is both unknown and highly variable.

Steel and cast-iron pipes are plagued by corrosion and repairs to these pipes are constantly needed. Aspects of the corrosion problem include disbonding of protective coatings and stress-corrosion cracking. Location of problem areas is difficult and repair of these lines is often disruptive, expensive, and short-lived.

Polyethylene piping is proving itself to be a viable alternative in sliplining existing piping and installing new, more durable plastic piping in place of corroded pipe. Though virtually free from attack by corrosion, plastic piping faces its own challenges of squeeze-off damage, inadequate heat fused jointing, and failures due to overbending, electrostatically caused pinholes, and locating the plastic piping underground.

In addition to the problems associated with preventing, detecting and locating leaks and failures in water distribution systems, there are problems associated with maintaining water quality within the system. For example, the effectiveness of water treatment chemicals decreases the further the product gets from the plant. The level of treatment is variable, especially in rural areas where budgeting constraints do not allow for needed capital investment. It is not uncommon in rural areas for temporary "boil orders" to be issued.

## Research Question

What are the best approaches to design, construct, maintain and rehabilitate water distribution systems and to ensure water quality in urban settings?

## Research Needs

Develop and demonstrate new and improved technologies to prevent, detect, and locate leaks in water distribution systems and to restore/rehabilitate sites where leaks have occurred.

Develop cost-effective technologies and policies that promote both conservation of water as well as overall improvement of water quality.

## Research Program Areas (not prioritized)

**A.1.1** Identify and evaluate the primary causes and effects on water quality of leak failures in water distribution systems and assess the state-of-the-art associated with preventing, detecting, locating, and rehabilitating these leaks/failures.

**A.1.2** Identify, design and construct required modifications to the UWRF to enable testing of new and improved technologies for preventing, detecting and locating leaks in water distribution systems.

**A.1.3** Evaluate the application of acoustic technologies for more accurate and timely detection and location of leaks in potable water pipeline systems, recognizing the unique problems associated with varying pipe materials, connections, and types of lines [i.e.,house service lines, laterals (12 in dia), distribution lines ($\geq$ 24 in dia; 24 dia),etc.].

**A.1.4** Evaluate other-than-acoustic principles for detecting and locating leaks in water distribution systems and develop a matrix associated with what systems are more applicable to specific situations; e.g., system configuration, pipe size, material, etc..

**A.1.5** Investigate innovative approaches to "build in" leak prevention/detection/location capabilities.

**A.1.6** Identify and assess the state-of-the-art on technologies to determine and predict the structural integrity of water distribution systems.

**A.1.7** Evaluate the application of acoustic technologies (and other nondestructive technologies) to assess the structural integrity of water distribution systems and to assist in approaches to predict potential system failures.

**A.1.8** Evaluate improved design and installation procedures associated with water distribution systems, including:

--- guidance on materials selection and inspection to ensure compliance with water quality standards and compatibility with site-specific conditions
--- excavation technologies, involving no-dig, low-dig, quiet-dig techniques

--- improved backfill materials and processes

**A.1.9** Investigate the primary causes of system failures and develop improved evaluation, operation and maintenance programs, and mechanisms to protect the integrity of water distribution systems.

**A.1.10** Evaluate computer-aided systems and remote monitoring and control techniques for decision making on water pipeline operation, maintenance and repair.

**A.1.11** Identify and assess the state-of-the-art on repair and replacement techniques for damaged water distribution systems, including:

--- methodologies for locating plastic piping underground
--- techniques relating to disinfection after repair or replacement
--- techniques for rehabilitating or replacing lead service lines

**A.1.12** Evaluate techniques such as the use of $C0_2$ treatment for removing and controlling scale without disruption or health hazard, in domestic water systems.

**A.1.13** Identify and evaluate new and improved technologies such as baked-on phenolic coatings for copper lines to prevent internal scaling and corrosion.

**A.1.14** Evaluate new and improved techniques such as *in situ* epoxy linings for rehabilitating and prolonging the life of existing water mains inplace.

**A.1.15** Evaluate the performance of pipe corrosion inspection crawlers with optical probes to determine the integrity of small diameter pipes.

**A.1.16** Evaluate new and improved techniques such as "pipe bursting" to replace old utility lines with polyethylene pipe.

**A.1.17** Evaluate the problems associated with water system appurtenances such as: valves, regulators, connections, etc., including their contribution to impeding more accurate leak detection and leak location, and investigate new and improved design concepts to prevent leakage.

**A.1.18** Assess current design technologies and practices associated with conserving water and maintaining water quality in the distribution system and investigate new approaches, policies and design and treatment concepts.

## A.2 CONVEYANCE SYSTEMS: PETROLEUM AND CHEMICAL

Approximately 3 million storage facilities in this country contain petroleum products and other chemicals.[8,9] Associatedwith these systems are thousands of miles of pressurized pipelines, both above ground and below ground. Most of the earlier installed systems were made of bare steel, which is likely to corrode over time and allow contents to leak into the environment. Faulty installation or inadequate operating and maintenance procedures can also result in uncontrolled releases.

A pressurized pipeline system can remain functional and disperse product even if it is leaking. Because of the high operational pressures, a large release can occur in a very short period of time. Even a small release, such as a single gallon of gasoline can render a million gallons of water non-potable. The average clean up cost of a leak is estimated by the U.S. Army Environmental Center to be approximately $200K and ranges considerably higher where ground water is contaminated.[10]

A survey conducted by API in July 1994 indicated that pressurized buried piping has been the most predominant source of contamination over the past five years.[9] An earlier survey indicated that approximately 70-80% of the leaks in storage systems occurs in the pipelines; mostly pipelines under pressure.

Federal regulations require that the owners of petro/chemical tank systems test their pipelines using leak detection systems that meet minimum performance standards. No leak detection system can be used unless it can be certified as capable of meeting these federal standards (*i.e.*, 3 gal/h for automatic leak monitors, 0.1 gal/h for line tightness test methods, and 0.2 gal/h for automatic monitoring methods).[11]

Older systems are being replaced with newer technologies (*e.g.*, double-walled lines, flexible piping, fiberglass lines). These newer technologies do not have a long history of performance in the field and accordingly are introducing new problems in dealing with preventing, detecting and locating leaks.

In addition, there is a tremendous variety of pipeline configurations being utilized for petro/chemical distribution, each having unique characteristics and unique problems associated with preventing, detecting and locating leaks. These include conveyance systems typically found at retail service stations, military installations, bulk product storage and dispensing facilities, airport hydrant systems, trans-continental pipelines, railway cars and other transfer lines.

## Research Problem

There are four main technologies in use for detection of liquid leaks; each is associated with the physical phenomena which occurs either at a leak site or in the system due to the leak. Chemical concentration detection or "sniffing" requires the leakto provide concentrations which are detectable above normal, naturally occurring concentration levels. Level monitoring can be used only in closed systems which allow for an accounting system to detect losses. Supervisory control and data acquisition systems rely on process control sensors to detect discrepancies in the performance of the system which could indicate a leak. Acoustic systems rely on noise produced by turbulent liquid flow to detect leaks in piping systems. Each of these technologies has a specific detection sensitivity and each has advantages and disadvantages associated with the system it is used with. In addition, these technologies, except for acoustics, predominantly detect leaks as opposed to actually locate leaks and require long test times which can seriously impact normal operations and increase environmental risks.

Other technologies that physically inspect the internal surface of pipelines utilize ultrasonics, fiber optics, and video inspection in combination with robotic technology. Additionally, transcontinental pipelines, typically utilize "pigs" for internal inspection. These approaches have their place in the matrix of problem and system application; however, some are in the developmental stage and others are costly, obviously invasive, and require downtime to conduct a test.

## Research Question

What are the best approaches to design, construct, maintain and rehabilitate petro/chemical distribution systems to ensure optimum system performance and thus reduce the risks (associated with failure) to public health and safety?

**Research Need**

Develop and demonstrate new and improved technologies to prevent, detect, and locate leaks in petro/chemical distribution systems and to restore/rehabilitate situations where leaks have occurred.

**Research Program Areas (not prioritized)**

**A.2.1** Document the primary causes of leaks, and failures in petro/chemical distribution systems and assess the state-of-the-art and inherent problems associated with preventing, detecting, locating and rehabilitating these leaks and failures. Investigate systems/aspects of systems of varying materials of construction, sizes and configurations, as utilized for specific applications, such as:

- --- fuel dispensing lines at retail service stations
- --- fuel transfer lines at military installations
- --- regulated bulk product lines such as hydrant systems, transcontinental systems, etc.
- --- production lines in chemical manufacturing industries
- --- system appurtenances such as valves, elbows, bends, transition sections, etc.
- --- transportation systems such as rail tank cars and other transfer vessels, etc.
- --- low level liquid waste systems at DOE installations

**A.2.2** Identify, design and construct the required modifications to the UWRF to enable testing of new and improved technologies for preventing, detecting, and locating leaks in the petro/chemical distribution systems investigated in Research Area A.2.1.

**A.2.3** Evaluate the application of passive acoustic technologies for rapid, nonintrusive, portable and online, detection and location of leaks in petroleum distribution lines found at:

- --- retail service stations (typically 2-4 in dia, 200 ft long)
- --- fuel transfer lines at military installations (typically 10-12 in dia, 500 ft and longer)

--- low level liquid waste lines at DOE installations (typically double-walled lines, 4 in inner dia/8 in outer dia, several thousand feet long)

**NOTE**: This is an ongoing program sponsored by DoD

**A.2.4** Evaluate other-than-acoustic principles for detecting and locating leaks in petro/chemical distribution systems and develop a matrix associated with what systems are more applicable to specific situations.

**A.2.5** Evaluate new design and installation procedures and technologies such as "built in" leak prevention, detection, and location capabilities associated with petro/chemical distribution systems.

**A.2.6** Identify and assess the state-of-the-art on technologies to determine and estimate the structural integrity of petro/ chemical distribution systems; *e.g.*:

--- fiber optic instrumentation

--- diagnostic computer program to evaluate cathodic protection systems and predict corrosion

--- computer systems to prioritize pipeline repair/replacement

--- pipe corrosion monitor using electro chemical impedance to avoid "dig-up"

--- fracture/fatigue systems to minimize failures

**A.2.7** Evaluate the application of acoustic technologies (and other nondestructive technologies) to assess the structural integrity of petro/chemical distribution systems and to assist in approaches to predict potential system failures.

**A.2.8** Evaluate the problems associated with petro/chemical appurtenances and develop new and improved design concepts and other solutions, including such items as:

--- losses due to intrinsic valve leakage into the flare system which can cost many hundreds of thousands of dollars per annum on any individual site. (A simple practical system for quantifying leaks from individual/multiple valves can be developed to assist in maintenance decisions.)

--- the contribution of transition sections, elbows, bends, etc. to impeding more accurate leak detection and leak location technologies

**A.2.9** Investigate improved operation and maintenance methodologies and programs, including remote monitoring and control approaches, to improve system performance, to reduce risks to the environment and to operating personnel from premature failures.

**A.2.10** Identify and assess the state-of-the-art on repair and rehabilitation technologies for damaged distribution systems and investigate new and improved technologies; *e.g.*:

--- sliplining technologies
--- inliner cured inplace pipe
--- *in situ* form cured inplace liner

**A.2.11** Identify the state-of-the-art and needs associated with the prevention, detection and repair of leaks in transportation systems such as rail tank cars and other mobile vessels.

## A.3 CONVEYANCE SYSTEMS: STORMWATER AND WASTEWATER

Sewer pipeline stoppages and collapses are increasing at a rate of approximately 3% per year. Roots that puncture and grow inside pipes cause over 50% of the stoppages, while a combination of roots, corrosion, soil movements and inadequate construction are the cause of most structural failures. Deterioration of jointing materials, pressure surges, disturbance by construction or direct tapping, and seismic activity also contribute to collection line failures. These problems result in approximately 75% of the nation's piping systems functioning at 50% of capacity or less.[4]

In addition to stoppages and collapses, infiltration (water seepage through the collection system pipes and vaults) can greatly increase flows and cause unnecessary burdens on the treatment plant. In some systems, lines become overloaded and uncontrolled overflows occur at unspecified locations. Since most sanitary sewers do not have overflow structures designedinto the system, overflows often occur through manholes and defective lines in residential neighborhoods causing backups into homes. In comparison to a combined sewer overflow, sanitary sewer overflows generally contain higher percentages of raw sewage and a lower level percentage of stormwater. Old sewer systems, constructed before 1970 using mortar or mastic jointing materials, can substantially contribute to infiltration. As a standard, EPA guidelines consider infiltration to be excessive if the flow to the treatment plant is greater than 120 gpd/capita for non-runoff conditions.[12]

**Research Problem**

As with water distribution systems, leak prevention, detection, and correction in stormwater and wastewater collection systems is not a simple problem. Knowing leak status is critical for repair or replacement. Flow volume measurement, relatively simple when input data is available, becomes more problematical when input is both unknown and highly variable. Increased flows at the treatment plant indicate a problem, but do not isolate its location. Dye and smoke test methods frequently cannot locate small leaks. Most currently available automated pipe inspection systems are designed for smaller diameter distribution pipes. Varying pipe diameters, materials (including brick, concrete, ductile iron, and clay), odd shapes, sumps, and angle entries are not frequently suitable for robotic inspection systems. Sanitary sewer flows can carry disease, potential toxic substances, and other dangers. Physical inspection by workers is costly, disruptive to urban commerce and travel, and potentially dangerous to personnel and surrounding structures. Furthermore, replacement is expensive, especially in older systems which tend to crack, crumble, deteriorate and erode far faster than systems using modern materials.[4]

**Research Question**

What are the best approaches to assess, maintain and rehabilitate existing sewer systems and to construct new sewer systems in urban settings?

**Research Need**

Develop and demonstrate new and improved technologies that can be used to construct, maintain, and repair new and existing sewer infrastructure at an acceptable cost.

**Research Program Areas (not prioritized)**

**A.3.1** Evaluate and document the results of multiple rehabilitation approaches on infiltration/inflow reduction on anational basis.

**A.3.2** Develop a methodology to evaluate the adequacy of operation and maintenance programs for collection systems.

**A.3.3** Develop an optimized approach for maintaining collection systems.

**A.3.4** Review and evaluate current sanitary sewer design and installation practices (including materials for improved structural performance) and recommend improvements.

**A.3.5** Develop and evaluate new and improved coupling techniques and house service laterals to significantly alleviate infiltration and inflow problems.

**A.3.6** Develop methods and evaluate the benefits of reducing impervious areas to alleviate stormwater runoff quality and hydraulic impacts to surface waters.

**A.3.7** Evaluate the advantages and disadvantages of using side grass swales and other methods instead of curbs and gutters to reduce the quantity of polluted stormwater runoff entering receiving waters.

**A.3.8** Evaluate current technologies, identify, and develop new and improved technologies to detect and locate leaks in sewer systems and to evaluate their structural integrity.

**A.3.9** Evaluate current repair/replacement methodologies for collection systems and investigate new and improved approaches.

**A.3.10** Identify and develop approaches for "retrofitting" existing wastewater treatment plants and pumping stations to expand their treatment capabilities without major expenditures.

**A.3.11** Evaluate physical, chemical and thermal methodologies for removing roots and improving flow rates in collection systems.

**NOTE**: Most of the above Research Program Areas are being addressed under NRMRL's Wet Weather Flow Research Plan.[13]

# A.4 CONVEYANCE SYSTEMS: HOT AND CHILLED WATER AND STEAM

District heating and/or cooling (DHC) consists of a central plant which distributes a medium through a piping network to multiple buildings. For heating, the medium is either steam or hot water; for cooling the medium is chilled water. DHC has a number ofenvironmental advantages. Treatment at a central source allows for significant improvement in air quality through reduction of emissions of NOx, $S0_2$, $C0_2$ and particulates. Additional gains in environmental quality are achieved through the use of gas fired co-generation facilities where the waste-heat from the generation of electricity is reclaimed and used for district heating. This resource-recovery approach increases efficiencies by the reduction in overall fuel use and associated emissions. Steam absorption chillers and other technologies provide chloro-fluorocarbon (CFC) free cooling at a fraction of the cost of replacing individual building systems. Additionally, the use of district cooling allows for the replacement of CFC-based cooling systems. These pollution prevention activities result in significant increases in environmental quality and compliance, and a subsequent and considerable increase in net fuel savings.

Another pollution prevention advantage of DHC is that of fuel flexibility. A central plant can be designed to burn multiple fuels which may be, or become available. This allows managers and plant operators the capability of selecting the most cost effective and/or non-polluting fuel on a regular basis. As energy becomes increasingly deregulated such flexibility will be essential. In addition, the use of, or adaptation to, indigenous renewable fuels will also be possible.

**Research Problem**

The combination of improper design, installation or maintenance of DHC systems recurrently leads to environmental quality deterioration, the loss of energy resources and efficiency, and decreased system life. Efforts to make optimal use of limited environmental resources and capital improvement, operational and maintenance funds are hampered by an inability to accurately estimate future system conditions.

A related problem is that every potential use of DHC represents a unique situation that requires an analysis and estimation of many factors. A few examples of such factors include: local and regional air quality, user density, load types and proportion, local fuel costs and availability, terrain and site conditions, local regulations and economy, applicable environmental regulations, weather conditions, and projected growth. Decision tools are needed to efficiently assist in the complex process of choosing among multiple alternatives.

## Research Question

What are the best methods to design, construct, maintain, rehabilitate, improve and promote the use of district heating and cooling without jeopardizing environmental quality.

## Research Need

Evaluate, develop and demonstrate new and improved approaches and technologies to design, construct, operate and maintain, repair and rehabilitate district heating and cooling systems.

## Research Program Areas (not prioritized)

**A.4.1** Identify the state-of-the-art on preventing, detecting and locating leaks in district heating and cooling systems.

**A.4.2** Assess current design, construction, operation and maintenance practices for district heating and cooling systems, including materials selection and system repair and rehabilitation techniques.

**A.4.3** Develop and adapt computer-based decision tools for optimal choices between environmental criteria and energy and distribution alternatives.

**A.4.4** Develop a low maintenance sensor system to monitor boiler and cooling tower chemistry and automatically adjust the treatment chemical input to reduce the potential of an environmental hazard if released.

**A.4.5** Investigate and better quantify the condition prediction of DHC components and materials so as to better allocate maintenance funds.

**A.4.6** Identify current design approaches and develop new approaches (such as a standard shallow trench design) that incorporate the best features of the various operational systems currently in use.

**A.4.7** Develop an engineering system for the management of various types of distribution systems and components to assure optimal use of maintenance funds.

**A.4.8** Develop remote sensing technologies to determine system condition and energy efficiency in real time, emphasizing the development of accurate and long-lived heat flux sensors and a durable manhole high-water alarm.

**A.4.9** Develop an acoustic leak detection sensor system for use on energy distribution systems.

**A.4.10** Develop a quantitative infrared assessment system to non-invasively determine a systems current performance.

**A.4.11** Develop a durable high temperature insulation which canwithstand medium durations of boiling water while retaining a large portion of its insulating properties.

**A.4.12** Investigate the lessons learned by the private sector during the privatization of district heating and cooling systems.

**A.4.13** Investigate new methods to better water-proof manholes during new construction and rehabilitation.

**A.4.14** Develop high performance coatings to prevent scale buildup in heat exchangers.

**A.4.15** Investigate enhanced thermal heat capacity mediums for thermal distribution to allow for comparable energy delivery while using smaller diameter pipes.

**A.4.16** Develop durable high performance, polymeric multi-strand heat exchanger tubing for greater efficiency and longer service life.

## B.1 STORAGE SYSTEMS: POTABLE WATER

Many water distribution systems in the United States are approaching 100 years of age and are in poor condition. Conservative design philosophies, an aging water supply infrastructure, increasingly stringent drinking water standards, and increasing demands for potable water associated with expanding urban areas are causing concerns over the viability of drinking water systems in the United States.

Storage tanks and reservoirs are the most visible components of a water distribution system but are generally least understood in terms of their impact on water quality. They play a major role in providing hydraulic reliability which includes adequate water quantity and pressure for fire-fighting needs as well as domestic and industrial demands. To meet these goals large amounts of storage are usually incorporated into the design of the distribution systems.[14]

**Research Problem**

Storage tanks and reservoirs can serve as vessels for complex chemical and biological changes that may result in the deterioration of water quality. Key factors in this effect are residence times and mixing characteristics. Large storage facilities experience long residence times which can contribute to chlorine residual loss and possible increases in the level of micro-organisms. Complete mixing maximizes the contact of chlorine with water volume in a tank; consequently, effectivetank design and operation are critical to maintain water quality at the maximum degree possible.

Storage facilities commonly employed for individual water supply systems include pressure tanks, elevated storage tanks, ground-level reservoirs and cisterns. Materials of construction for storage facilities that supply relatively small systems include concrete, steel, brick and sometimes wood (above the land surface). Many facilities fail because of loss of structural integrity making them susceptible to contamination and contributing to the loss of valuable resources. Determining the structural integrity of storage systems, selecting suitable construction and replacement materials, and locating facilities to protect them from potential contamination requires more serious consideration.

**Research Question**

What are the best approaches to assess, construct, operate and maintain potable water storage and treatment systems to ensure optimum system performance and thus reduce the risks to public health and safety?

**Research Need**

Evaluate, develop and demonstrate new and improved approaches and technologies to design, construct, operate, maintain, and repair potable water storage and treatment systems.

**Research Program Areas (not prioritized)**

**B.1.1** Document the primary causes of leaks and failures in potable water and treatment facilities and assess the state-of-the-art on preventing, detecting, locating and rehabilitating these leaks and failures.

**NOTE**: The Research Areas associated with the physical aspects of preventing, detecting and locating leaks in potable water storage facilities are similar to those for petroleum/chemical storage facilities (*i.e*. tanks, Section B.2) and stormwater storage facilities (*i.e.* earthen impoundments, Section B.3); accordingly, they will not be addressed here to avoid redundancy.

**B.1.2** Assess current approaches to the design (including materials selection), construction and installation (including facility location) of potable water storage systems and suggest improvements to enhance mixing, extend the structural life of the system, and prevent potential contamination from the loss of structural integrity.

**B.1.3** Evaluate how operating conditions, tank geometry and the location and design of inlet/outlet pipes influence the mixing regime in tanks.

**B.1.4** Assess the applicability of multi-compartment models to varying system geometry and operation conditions.

## B.2 STORAGE SYSTEMS: PETROLEUM/CHEMICAL

During the 1950s and 1960s, hundreds of thousands of storage tanks containing petroleum products and hazardous chemicals were installed. Approximately 90-95% of the "regulated" underground storage tanks (USTs) (about 2 million in the 100-15,000 gal range) contain motor fuels and petroleum products; the remainder contain hazardous chemicals.[8] In addition to underground tanks, there are approximately 2.5 million aboveground storage tanks (ASTs) associated with the bulk storage of oil and with the production, refining, transportation and marketing sectors of the petroleum industry. This number appears to be growing with some owners of USTs, primarily those with non-retail operations, closing those tanks and replacing them with ASTs, or installing new ASTs instead of USTs. The primary incentive for this action appears to be (1) cost savings in avoiding the UST regulations, which are seen as stricter and more costly than current AST regulations, and (2) the relative ease of monitoring ASTs for leaks.[15,17]

Most of these tanks were made of bare steel, which is likely to corrode over time and allow contents to leak into the environment. Faulty installation or inadequate operating and maintenance procedures also can cause releases. Many of these tanks have either been abandoned or have exceeded their useful life and are leaking suspected carcinogens such as benzene, MTBE, etc.. The threat from leaking tanks is not, however, limited to ground water. Leaking petroleum and chemicals can also contaminate surface waters and contribute to air pollution. In addition, these products release vapors that can seep into the sewerage systems of homes and businesses and accumulate to explosive levels.

Today, more than 300,000 releases from USTs have been confirmed. The EPA estimates that as many as 20 to 25% of the regulated underground systems nationwide either are leaking or expected to leak in the near future.[16] Federal regulations for USTs set minimum standards for new tanks and require owners of existing tanks to upgrade, replace, or close them. The technical regulations are designed to reduce the chance of releases, detect and report leaks when they occur, and secure a prompt cleanup.[11]

ASTs are regulated by the Spill Prevention Control and Countermeasures (SPCC) Regulation[22], and subsequent revisions, which requires facility owners and operators to report oil discharges only if they trigger the reporting thresholds of the Clean Water Act regulations. Consequently, some leaking oil that contaminates soil and ground water may not be recorded in national spill databases. Despite these data limitations, analysis of existing data provides definite insight to the problem; *e.g.*:

--- about 30% of all reported oil discharges from onshore facilities, or approximately 1,700 spills annually, are to secondary containment areas, many of which are believed to be unlined

--- 85% of refineries, 68% of marketing facilities, and 10% of transportation facilities have known groundwater contamination near their facilities

--- a study of 88 facilities having 1 million gallons or more of aboveground storage capacity found that 88% of these facilities reported groundwater contamination

--- a study of 75,000 vertical ASTs greater than 42,000 gallons indicated that about 10,600 could be leaking between 43 and 54 million gallons of oil annually[18]

Although there is uncertainty about the number of leaking ASTs and volumes of product affecting soil, ground water, and surface water, EPA believes that sufficient evidence exists to recommend additional data collection and programmatic action. EPA is currently revising the SPCC Regulations to address tank construction and installation, integrity testing, containment measures to prevent leaks, and leak detection.

Petro/chemical products are also stored in earthen impoundments (*i.e.*, pits, ponds, lagoons). The research activities associated with the physical aspects of preventing, detecting and locating leaks in earthen impoundments are sufficiently similar to those associated with storing stormwater (Section B.3); accordingly, they will not be addressed here to avoid redundancy.

**Research Problem**

Leaks and discharges from storage facilities can be attributed to several causes. Equipment failure and human error are frequent causes; *e.g.*, overfilling and other mistakes during product transfer and handling activities; vandalism; failure and wear of piping and tanks; etc.. Most leaks occur in the piping or in malfunctioning valves (refer to Section A.2, Conveyance Systems: Petroleum/Chemical); however, shifting of tank foundations and corrosion contribute significantly to tank leaks.

Tests for detecting leaks are not straightforward in their implementation and interpretation, particularly as tank size,characteristics, contents and environmental parameters change. Additionally, not all leak detection systems are reliable for varying tank sizes; *e.g.*; inventory control techniques are of questionable reliability as tanks increase in size. Many testing procedures require time and temporary shutdown of the tank systems during testing, frequently resulting in lost revenue.

Results of an API research study on the strengths and weaknesses of leak methods for ASTs indicate that accurate and reliable leak detection is possible using both passive acoustic principles and volumetric methods. The study identified important features necessary to achieve high performance leak detection with these technologies; additional verification is required.[18] The development of an accurate leak simulator, for assessing AST leak detection technologies, would enable leak detection verification and testing on a variety of existing tank designs without the need to introduce a leak in a non-leaking tank. This would greatly enhance the cost effectiveness of an AST leak detection program.

**Research Question**

What are the most cost-effective approaches to design, construct, maintain and rehabilitate petro/chemical storage systems to ensure optimum system performance and thus reduce the risks (associated with failure) to the environment?

**Research Needs**

Develop and demonstrate new and improved technologies to prevent, detect, and locate leaks in petroleum/chemical storage systems, including below and aboveground tanks and earthen impoundments (pits, ponds, and lagoons), and to restore/rehabilitate situations where leaks have occurred.

**Research Program Areas (not prioritized)**

**B.2.1** Document the magnitude and primary causes of leaks and failures in petroleum/chemical storage facilities and assess the state-of-the-art on preventing, detecting, locating and rehabilitating these problems, including facilities such as:

--- steel tanks below and above ground (<1000 gal; 1000 gal to 25,000 gal; 25,000 gal to 50,000 gal; >50,000 gal)
--- fiber-reinforced plastic (FRP) tanks below and above ground (<25,000 gal; 25,000 to 50,000 gal)
--- pits, ponds, lagoons both lined and unlined

**B.2.2** Identify, design, and construct the required modifications to the UWRF to enable testing of new and improved technologies for preventing, detecting and locating leaks in thepetroleum/chemical storage facilities investigated in Research Area B.2.1.

**B.2.3** Evaluate the application of acoustic and nonacoustic technologies to detect and locate leaks in underground and aboveground storage systems of various sizes, materials of construction and contents, and develop a matrix associated with what systems are most applicable to specific situations.

**B.2.4** Evaluate current design and installation procedures and new technologies, such as "built in" leak prevention, detection, and leak location capabilities, and recommend improved approaches to prevent failures and to extend the useful life of a system.

**B.2.5** Identify and assess the state-of-the-art on technologies that can assess and monitor the structural integrity of petroleum and chemical storage systems and evaluate the application of acoustic and other nondestructive technologies to determine structural integrity and develop approaches that can reliably estimate system failures.

**B.2.6** Document the performance of fiber-reinforced plastic (FRP) tanks both below and above ground and recommend improved design, installation and rehabilitation procedures.

**B.2.7** Evaluate the performance of existing storage systems that were originally designed to store conventional petroleum products and are now being used to store alternative fuels which have higher alcohol contents.

**B.2.8** Document the state-of-the-art on the detection and location of leaks in storage systems used to store alternative fuels.

**B.2.9** Assess the state-of-the-art on storing petroleum and chemicals in lined and unlined pits, ponds, and lagoons and identify improved leak prevention, detection and location capabilities.

**B.2.10** Select and demonstrate a leak simulator for assessing AST leak detection technologies.

**B.2.11** Investigate improved operation and maintenance programs to reduce risks to the environment and to operating personnel from premature failures.

**B.2.12** Identify and assess the state-of-the-art on repair and rehabilitation technologies for damaged storage systems and investigate new and improved technologies.

**B.2.13** Evaluate emission techniques which can identify and locate partial discharge sources in oil-filled transformers.

**B.2.14** Evaluate the application of acoustic emissions technology to prevent, detect and locate leaks in production systems, such as:

--- thick-walled, high temperature pressure vessels, where the stresses resulting from cooldown may be sufficient to stimulate defects which can be identified with acoustic technology; monitoring the cooldown provides information for scheduling further inspection and maintenance to prevent failure

--- process reactors with refractory linings which present a particular challenge for re-qualification because the removal of the lining to allow internal inspection is costly and can result in subsequent reliability problems; acoustic procedures for testing these vessels can be used online or during pneumatic tests

## B.3 STORAGE SYSTEMS: STORMWATER/WASTEWATER

Storage is considered a necessary control alternative for wet weather flows because of the high volume and variability associated with stormwater and combined sewer overflows. Some of the most critical problems currently facing wastewater management agencies are the control of Infiltration/Inflow (I/I)-induced sanitary sewer overflows (SSOs) and treatment facilities, including hydraulic overloading and disruptions of biological and other plant processes. As agencies examine alternative approaches to controlling I/I problems, storage facilities are increasingly being planned, designed, and constructed for the control of wet weather flows in sanitary sewer systems. While storage facilities have commonly been constructed at wastewater treatment facilities (where they are referred to as equalization basins) to maximize the processing of wastewater generated during wet weather while protecting the plant processes from hydraulic overloading or biological disruption, the use of storage at upstream locations within the collection system has only recently begun to gain acceptance. Collection system storage facilities are now being recognized as providing much of the benefit to treatment facilities realized with equalization basins, with the additional benefit of controlling SSOs and basement flooding while minimizing or eliminating the need to construct relief sewers.[12]

Wet weather flow storage facilities may be constructed inline or offline. These facilities can be constructed inland and upstream, on the shoreline, or in the receiving water. In addition to storage, other functions of these facilities may include sedimentation (and associated toxics removal), dryweather flow equalization, flood protection, flow attenuation to enhance receiving stream assimilation, and hazardous material spills capture. The development of new and improved concepts for wet weather flow treatment and control is covered in NRMRL's Wet Weather Flow Research Plan.[13]

This plan predominantly addresses the structural aspects of stormwater and wastewater storage facilities. Conventional facilities are usually concrete or earthen basins or impoundments. During the last two years alone, hundreds of lives were lost, thousands of square miles of ecosystems were destroyed or devastated, and $50 billion of property damage was caused by the failure of these types of facilities due to excessive stormwater.

Besides these conventional wet weather flow related facilities, there are as many as 500,000 earthen-diked impoundments (pits, ponds and lagoons) in the United States containing potentially hazardous wastes. This total includes small waste ponds at minor chemical manufacturing plants as well as mile-square tailing lagoons at mines, smelters, and phosphoric acid plants. A common element between these similar systems is that a seemingly secure earthen impoundment may suddenly fail with provocation as slight as a heavy rain. These failures have resulted in the loss of life, caused the uncontrolled release of contaminants, polluted waterways, killed aquatic species, adversely impacted drinking water systems, generated public and political concerns, and despoiled scenic areas.

## Research Problem

Earthen impoundments, levees and dams generally consist of an embankment (with an upstream and downstream slope) and a base foundation. Such systems are constructed of a variety of soils; frequently, with the materials that were at hand. The resulting structures may be susceptible to sudden failure. Additionally, seepage may also reduce slope strength and contribute to failure, because it brings fluid to the downstream slope and thereby adds weight, increases the load, and decreases apparent cohesiveness and effective normal force. Failure through the base must be considered, particularly when the soil beneath the dam is softer than the slope-forming soil. In addition, unless adequate freeboard (embankment height above the maximum expected fluid level) is provided, failure can occur through overtopping.

Earthen impoundments are subject to overtopping and failure through the collection of rainwater, run-off or other uncontrolled inflow. Overflows are generally the result of insufficient capacity due either to insufficient freeboard or structural problems that reduce the effective capacity. No matter what the cause, impoundment overflows of hazardous wastescan pose significant environmental and public health risks through the contamination of soils, ground water, and surface water, as well as the potential to spread the contamination into areas not currently impacted by the impoundment.

Because this problem involves thousands of earthen impoundments and dams, and tens of thousands of levee-miles (six thousand in northern California alone) throughout the country, an inexpensive and simple technique for monitoring the stability of earthen dams is needed. The high cost of conventional methods of monitoring dam stability usually rules them out as candidates for evaluating failure potential of small waste dams. It seems unlikely that conventional methods of inspection, which require expensive instrumentation and trained geo-technical engineers, can meet the need.

Under this impetus, EPA ORD developed a prototypical acoustic emission monitoring system -- based on the phenomenon that soils emit sounds under stress. Initial research results demonstrated that the resulting acoustical signals, when properly amplified and quantified, can be valuable guides in evaluating the stability of earthen impoundments.[19] Recent advances in signal processing, computer hardware and software, and telemetry now provide a cost-effective platform from which these initial research efforts can be developed into an accurate, reliable and inexpensive system for monitoring the stability of earthen structures. Such systems will provide real-time data regarding the structural condition of remote earthen structures. This is especially critical during emergency situations since it would enable responsible officials to deploy limited resources to reinforce the most critical areas and avert catastrophic failures.

**Research Question**

What are the most cost-effective approaches to design, construct, maintain and rehabilitate storage systems for stormwater and wastewater to ensure optimum system performance and thus reduce the risks (associated with the failure of such systems) to the environment?

**Research Need**

Develop and demonstrate new and improved technologies to prevent, detect and locate leaks in storage systems used to store stormwater and wastewater and to restore/rehabilitate situations where leaks have occurred.

**Research Program Areas (not prioritized)**

**B.3.1** Document the magnitude and primary causes of leaks andfailures in systems used to store stormwater and wastewater and assess the state-of-the-art on preventing, detecting, locating and rehabilitating these problems; including sewer systems, end-of pipe storage systems and earthen impoundments (including dams and levees).

**B.3.2** Identify, design, and construct the required modifications to the UWRF to enable testing of new and improved technologies for preventing, detecting and locating leaks in the storage systems investigated in Research Area B.3.1.

**NOTE**: Research Areas in B.2.3, B.2.4, B.2.5, B.2.6, B.2.9, B.2.10, B.2.11, and B.2.12 address technical activities associated with storing petroleum and chemicals. The technology research approaches for these areas are related to and can be applied to the investigation of leak prevention, detection, and location in earthen impoundments. Accordingly, these technology areas are not repeated here to avoid redundancy.

# C. SUSTAINABLE TECHNOLOGY DEVELOPMENT

Sustainable development has been defined as "development that meets the needs of the present generation without compromising the needs of future generations."[21] A sustainable community exacts less of its environment in terms of land, water, resources and fuel and uses what it extracts as efficiently as possible. Sustainable development has the potential to alter the fundamental underpinnings of the relationship between humans and the natural environment, as well as political, corporate, and societal systems.

It has been estimated that, "the changes that society will experience over the next 20 years will be five times greater than that which we have witnessed over the last 100 years. Consider the advancements in medical care, communications, and transportation since 1892; multiply that change by five, and you will have a semblance of the world in the year 2012. There is no reason to believe that the water supply (and water resources) community will change any less."[2] As the American population and industrial base grows, increased demand for water has and will continue to force communities to use source waters of lesser quality. New and improved technologies are required to address this demand and to preserve water for the next millennium. To accomplish this, the water resources community must understand everything about its product and strive to improve the quality of water delivered to its customers and to protect water as a precious resource.[1]

In the context of this research plan, sustainable development would provide new and improved solutions to existing and emerging problems associated with the storage, conveyance, treatment anddistribution of water and wastewater. Such solutions would, for example, include consideration of renewability, recyclability and reuse, energy consumption, operating cost, waste and pollution reduction, and risk and liability. Preceding sections of this plan essentially addressed environmental improvements to existing problems; this section addresses future gains that could be realized from the design of long-term, anticipatory research.

**Research Problem**

The concept of a sustainable community must be approached at a variety of levels: at the level of the environmental context and local ecology; at the level of the local economy and its interconnections with other local, regional, national and international economies; at the level of the social and cultural mores and attitudes of the inhabitants of the community; at the level of the technology that underpins the community and enables it to function and grow. Few serious studies exist which rigorously and accurately evaluate and assess the cost/benefit relationship between widescale application of "sustainable" principles versus more market-driven, *laissez-faire* development.

Achieving sustainable development presents a challenge to deliver new and innovative infrastructure and facilities needed to serve society while protecting the environment. The introduction of new planning, design and operating concepts; new materials of construction; and more sophisticated treatment and reuse processes will mean additional contaminants for which potential health risks will need to be determined. Facilities are currently designed using least-cost technologies that ignore opportunities to improve productivity and to enhance environmental quality. In some cases, better technologies are available, but the capability to find and retrieve them is not there.

From a water and wastewater research perspective the initial problem is defining the principles associated with sustainable development in operational terms and identifying the opportunities to promote it. Before the industry can act to create sustainable infrastructure in these areas with confidence, there must be a clear, accepted delineation of the ways to identify, evaluate, and verify sustainability. Since the current understanding is conceptual, it must be supplemented by developing the parameters and the methods necessary to measure it. Key stakeholders must collectively agree upon these factors and upon a means for continually re-examining the issues and revising the definitions to keep pace with advancing knowledge. This research plan proposes to accomplish this for water and wastewater activities through measures such as the development of new analysis tools which include sustainability parameters, demonstration of the actual costs and benefits of sustainabledesign, and development of design approaches that incorporate the definition of sustainability within the process of setting project objectives and monitoring results.

**Research Question**

What are the parameters associated with "sustainable" water and wastewater systems, and how do we apply these parameters to the design, installation, operation and maintenance of these systems?

**Research Need**

To efficiently deliver safe, reliable, and functional infrastructure, while preserving and enhancing environmental quality.

**Research Program Areas (not prioritized)**

**C.1** Identify goal-setting practices and benchmark current high performance strategies associated with the design, construction and performance of conveyance, storage and treatment of potable water, petroleum and chemical products, and stormwater and wastewater to enable the development and evaluation of "nonstandard" innovative approaches.

**C.2** Define the principles involved in achieving sustainable development for water and wastewater resources; the objectives required to attain sustainability; and the decision tools and methods required to pursue innovative efficient planning, design construction, operation, maintenance, repair, recycling, and monitoring of the process; *e.g.*,

--- define sustainable development patterns, practices, and measures pertaining to design and establish new protocols, processes, guidelines and tools
--- identify principles of current practice that will transform current development patterns to a sustainable built environment
--- what are realistic and practical principles that are operationally defined and broadly accepted
--- consider renewal, recyclability, reuse and reduced operating costs, waste, and pollution
--- develop new analytical tools and data to quantify costs, benefits, and impacts
--- geographic, economic, social and cultural considerations (developing regions are experiencing rapid growth,

with the associated need for their infrastructure to support that growth --- at the same time, developed areas are replacing old and obsolete infrastructure to meet existing and future requirements)

--- develop centralized databases for exchange of information on planning and design principles and practices and infrastructure technologies

--- develop training and education programs on sustainability

--- develop a cost-benefit analysis framework that explicitly incorporates environmental impacts into the assessment of sustainable activities

**C.3** Identify the barriers that impede the adoption of innovative technologies and practices that support sustainable development (*e.g.*; procedures for project selection; inflexible and inappropriate rules, regulations, codes and standards; knowledge of state-of-the-art alternatives) and develop procedures and standards that will provide the flexibility to pursue sustainable development practices in an economically efficient manner.

**C.4** Identify and evaluate the application of "new-age", "high-performance" materials and systems developed for use in space to replace (repair, rebuild or expand infrastructure) current conveyance and storage materials and systems to enhance sustainability; *e.g.*,

--- establish performance criteria

--- collect real world data on innovative materials

--- develop models and methods that identify and gather data needed for cost analysis and environmental assessments

--- develop tools, databases and guidelines to support selection and analysis of alternatives

--- identify economic opportunities to recycle, reuse materials, and renew infrastructure and facilities

**C.5** Identify synthetic organic chemicals (SOCs) that could occur, and the risks of SOCs and inorganic chemicals (IOCs) from storage and distribution systems constructed of "new age" materials.

**C.6** Evaluate the mechanisms of SOCs in poor quality source waters and in highly treated wastewaters considered for direct reuse.

**C.7** Determine the potential risks associated with the reuse of sludges and other wastes associated with stormwater, wastewater, and drinking water treatment.

**C.8** Identify communities that have attempted to completely/ selectively plan and design for sustainable water and wastewater activities; evaluate their approach; monitor their performance; and develop demonstration projects with other communities to verify the performance of sustainable technologies in real world applications to promote their use.

**C.9** Develop a decision-support system for sustainable technology selection, including:

--- new tools and methods for advancing state-of-the-art technologies
--- life-cycle costing and eco-construction techniques
--- new predictive tools
--- educational and professional training programs
--- databases

**C.10** Develop improved quantitative decision-support tools to compare the costs and effectiveness of various remediation alternatives within a risk-based framework for significant, recurrent and critical risk management remediation situations in urban areas; *e.g.*, solvent sites, pesticides sites, and wood preserver sites, metal sites, lead battery sites, petroleum and chemical storage sites, etc.

EPA estimates that there are approximately 450,000 urban industrial sites that have fallen into disuse. Unpredictable cleanup costs often cause businesses to overlook these so-called brownfield sites in favor of untouched suburban or rural greenfield sites. This pattern of land use results in environmentally destructive urban sprawl. Most of these sites could be safely, sensible and economically restored for industrial use; however, the problem remains unpredictable standards. If the cleanup standards were better defined, the resulting value of the land would make it environmentally viable for private industry to cost-effectively clean up many of these sites.

# REFERENCES


1. "Creating the 21st Century through Innovation," American Society of Civil Engineers, Civil Engineering Research Foundation, Report #96-5016.E, 1996.

2. "Fragile Foundations: A Report on America's Public Works," National Council on Public Works Improvement, February 1988.

3. "Rebuilding the Foundations: A Special Report on State and Local Public Works Financing and Management," Office of Technology Assessment, OTA-SET-447, March 1990.

4. "State and Local Public Works Needs," American Society of Civil Engineers, Civil Engineering Research Foundation, December 1994.

5. "Safe Drinking Water from Small Systems: Treatment Options", Goodrich, J.A., Adams, J.Q., Lykins, B.W., Clark,R.M., EPA/600/J-92/236, May 1992.

6. "Developing a Data Base on Infrastructure Needs," Clark, R.M., Goodrich, I.A., Journal American Water Works Association, Vol. 81, No. 7, July 1989.

7. "The Tri-Service Environmental Quality R&D Strategic Plan," US Army Waterways Experimental Station, October 1994.

8. "Underground Motor Fuel Storage Tanks: A National Survey," EPA/560/5-86/013, May 1986.

9. "Aboveground Storage Tank Survey", prepared by Entropy Limited for the American Petroleum Institute, Publication No. 301, April 1989.

10. "Summary of Findings and Survey Results for Leak Detection Sensors for Water, Fuel and Energy Pipe Systems", Timmons,J., Weber, R.A., Hock, V.F., U.S. Army Corps of Engineers, Internal Document, September 30, 1996.

11. "Underground Storage Tanks; Technical Requirements and State Program Approval; Final Rules," 40 CFR 280 and 281, September 23, 1988.

12. "National Conference on Sanitary Sewer Overflows (SSOs), Seminar Publication," EPA/625/R-96/007, September 1996.

13. "Risk Management Research Plan for Wet Weather Flows," Field,R., et al, EPA ORD-NRMRL draft report submitted for publication, 1997.

14. "Mixing in Distribution System Storage Tanks: Its Effect on Water Quality," Clark, R.M., Abdesaken, F., Boulos, P.F., Mau, R.E., Journal of Environmental Engineering, pp 815-821, September 1996.

15. "Highlights of Forums on Aboveground Oil Storage Facilities," EPA Workgroup Letter Report, Lund, L., November 24, 1993.

16. "UST Strategic Tracking and Results System," EPA Office of

Underground Storage Tanks, March 1996.

17. "EPA Liner Study: Report to Congress," EPA Office of Solid Waste and Emergency Response, Pre-Decisional Document, September 27, 1995.

18. "An Engineering Assessment of Acoustic and Volumetric Methods of Leak Detection in Aboveground Storage Tanks," American Petroleum Institute Health and Environmental Affairs, Publications 306 and 307, October 1991 and January 1992.

19. "Acoustical System to Prevent Hazardous Material Dike Failures," EPA 625/2-79-024, 1979.

20. "Drinking Water and Health in the Year 2000," American Water Works Association Research Foundation, 1993.

21. "World Without End: Economic, Environment, and Sustainable Development," Pearce, D.W., J.J. Warford, Oxford University, Press 1993.

22. "Spill Prevention Control and Countermeasure Regulation", 40 CFR Part 112, December 11, 1973.

# APPENDIX A

## SELECTED INFRASTRUCTURE ISSUES RELATED TO NRMRL ACTIVITIES

### Water Resources Issues

· **Leak detection/repair of potable water transmission lines** must be accomplished more quickly, more accurately and more cost-effectively. The goal is to develop improved technologies to reduce the percentage of potable water losses in these pressurized systems, losses estimated to represent approximately 30% of the cost of water distribution on a national basis.

· **Stormwater runoff quality** cannot be assured; consequently, innovative management programs, such as considering runoff in the design of highways, communities, etc., are required. The objective is to utilize runoff as a resource by controling it at the surface.

· **Flood control for waterways** is typically accomplished by building protection structures such as floodwalls, levees, dams, control channels, or reservoirs. These structures have failed or overtopped due to inadequate design/design tools, (*e.g.* inaccurate modeling of channel hydraulics, underestimating runoff and design flows due to increased urbanization, etc.). The goal is to develop an inexpensive real time system for monitoring the structural integrity of such systems to prevent catastrophic failure.

· **Groundwater monitoring and detection** are required to maximize the likelihood of intercepting groundwater contaminated by leachate from municipal solid waste landfills and other sources, and to provide early detection. An area of concern when setting up a management system is the design, installation, and maintenance of the monitoring well network.

· **Groundwater well drilling and maintenance** technology development for drinking water purposes is often considered a lower priority than groundwater monitoring and detection. Application of modern construction techniques, including techniques developed for hazardous material monitoring wells, may assist the municipal well industry in complying better with Federal mandates.

### Wastewater Issues

· **Repair and rehabilitation of collection systems** is essential to prevent stoppages and collapses caused by root intrusion, corrosion, soil movement, inadequate construction, etc.. New technologies are needed to reduce the problem of infiltration, which can greatly increase flows and cause unnecessary burdens on the wastewater treatment plant.

· **Leak detection in collection systems** underlies decision making for repair and rehabilitation. Sewer infiltration leaks are common enough that the problem of treatment of excess groundwater is a serious source of extra costs for many wastewater treatment systems. Ideal technologies would rapidly detect new leaks and inform operators of the exact location, extent, and character of the leak (*i.e.*, infiltration or exfiltration).

· **Management of worker health and safety** is especially critical to the wastewater treatment industry since historically it has experienced one of the highest rates of accident frequency and severity of all industries reporting to the National Safety Council.[4] The nature of wastewater and its byproducts as well as the treatment process and equipment create "abnormal" atmospheres and working conditions. Breakthrough technologies that completely change the way in which wastewater is treated could radically improve the safety of treatment plant workers.

· **Maintenance and repair of treatment systems** is critical to keeping discharge waterways pathogen and pollution free. Ideal technologies would eliminate the breakdown factors that generate maintenance problems through improved design and construction approaches.

### Power and Energy Issues

· **Leak detection for storage tanks (UST and ASTs)** is required by federal regulations. There are numerous methodologies being employed; however, there is a need to document the performance of the various technologies as they apply to various size tanks (small process tanks, bulk tanks, etc.) and products (alternative fuels, hazardous chemicals, etc.). Improved technologies are also needed for quicker and more accurate leak location as well as detection, and in particular, leak prevention.

· **Leak treatment and cleanup for USTs, ASTs and pipelines** involves stopping and containing the leak or spill,determining the location of the source and extent of contamination, preventing further migration, and cleaning up the contaminated site. Faster, cheaper and more effective cleanup technologies are required that focus on risk-based approaches and the use of alternative and innovative cleanup technologies.

· **Leak detection for utility pipelines** must be accomplished quickly, accurately and cost-effectively. Approximately 75% of the leaks in underground storage systems occur in the pipelines; mostly pipelines under pressure. As with underground tanks, but more importantly for pressurized pipelines, the need is for preventing and locating leaks, as well as for detecting leaks, in pipelines of varying sizes, materials of construction and products.

· **Aboveground storage alternatives to underground storage tanks** are becoming more common because of fewer associated federal regulations, less red tape and insurance liability, lower initial costs and easier installation and leak monitoring problems. However, there are still many challenges to the use of ASTs:

--- initial installation costs may be lower, however, long-term maintenance must be considered
--- ASTs can require additional real estate
--- from a fire standpoint, USTs are safer; however, technological advances in AST designs could overcome this
--- containing a leak from an AST may be more problematic since concrete is the most popular containment material
--- vapor control is a very important consideration with ASTs
--- extra security measures may be necessary for an AST system to prevent vandalism

· **Repair of utility pipelines** involves hundreds of millions of dollars each year due to corrosion problems in steel and cast-iron pipes that carry gas and other fuels. These costs are expected to increase, since over half of the pipeline network using these materials was installed before 1960. A better understanding of the cause and effect of pipeline corrosion is needed, as well as cost-effective strategies for assessing, preventing and rehabilitating corrosion.

### Hazardous Waste Issues

· **Alternatives to landfill disposal** are required as existing landfills are closed and incinerators that do not meet airquality requirements are shut down. Potential solutions

have similar concerns as landfills; *e.g.*, possibility of fire, explosions, production of toxic fumes, improper management of incompatible waste and the possibility of contamination of surface and ground waters.

· **Spills and cleanup technologies** should focus on more timely and cost-efficient approaches to: contaminated groundwater plume management, surface water controls, gas controls, treatment of liquid waste streams, treatment of sludges and soils, and *in situ* treatment technologies.

· **Groundwater pollution monitoring/containment** technologies are needed to determine whether hazardous wastes are leaking from a treatment, storage, or disposal facility at levels great enough to warrant compliance monitoring; and to evaluate the concentrations of hazardous constituents in groundwater to determine whether corrective actions are required.

### Transportation Issues

· **Drainage of highways and roadways** can present flood, maintenance, and wastewater problems. Current designs do not adequately address installation and maintenance approaches that could prevent flooding and reduce contamination from roadway runoff.

· **Roadway snow removal and de-icing** must be coordinated in an environmentally conscious and efficient manner, while ensuring safe and passible roads during cold weather conditions. Guidance is needed for decision making on which of the numerous de-icing agents to use, what is their environmental impact, and how to spread them in the most effective manner.

# APPENDIX B

## NRMRL'S URBAN WATERSHED RESEARCH FACILITY (UWRF):INFRASTRUCTURE TEST APPARATUS

The Infrastructure aspect of the Urban Watershed Research Facility was originally designed and constructed to represent a full-scale equivalent of a commercial underground tank facility that can be operated under the controlled conditions necessary to obtain reproducible test results. The setup consists of two 8,000 gal underground tanks (one made of coated steel, the other of fiberglass); secondary containment(a synthetic membrane) for each tank; 3,000 gal and 6,000 gal aboveground tanks with heat exchange coils; a 154,000 Btu/h electric heater and a 60,000 Btu/h chiller; 400 gal minimum transfer circulation pumps; and monitoring wells (both inside and outside the secondary containment). The apparatus was designed to simulate leaks of different sizes and to provide maximum control over the major factors that affect the performance of release detections systems for tanks.

A full-scale pipeline test apparatus was also constructed and incorporated into the tank apparatus to support the development of pipeline release prevention and detection technologies. The original apparatus consisted of two 200 ft, 2 in diameter pipelines; one line made of fiber-reinforced plastic and the other of steel. The system was instrumented to allow for monitoring of the product in the line, the backfill, the operating characteristics of the line, and all appurtenances on the line. It was pressurized, and leaks were stimulated and detected.

The early research work at the UWRF led to a major ongoing multi-agency pipeline leak location research program sponsored by the DoD's Strategic Environmental Research & Development Program (SERDP). As part of this program, NRMRL's UWRF is undergoing extensive modification, including the installation of several representative pipeline test systems, to specifically develop acoustic technologies for more accurate detection and location of leaks in pressurized pipelines. SERDP funds are restricted to the development of acoustic technology for specific DoD pipeline problems. Many of the Research Program Areas discussed in this plan could be examined at the UWRF in a cost-effective manner by modifying the SERDP sponsored systems to enable the investigation of acoustic technology for other than SERDP applications and to investigate other than acoustic technologies.

# TABLE 1: HIGHEST PRIORITY INFRASTRUCTURE PROBLEMS AND NEEDS**

**WATER RESOURCES ISSUES**

NPDES Compliance for Stormwater
* Leak Detection/Repair of Transmission Lines

SDWA Compliance for Potable Water

Stormwater Flood Management
* Stormwater Runoff Quality
* Flood Control for Waterways
* Groundwater Monitoring and Detection
* Well Drilling and Maintenance

**WASTEWATER ISSUES**
* Repair/Rehabilitation of Collection Systems
* Leak Detection in Collection Systems

Regulations for Treatment Systems
* Management of Worker Health and Safety
* Maintenance/Repair of Treatment Systems

Land Applications for Sludge Disposal

Composting/Recycling of Sludge

Monitoring of Treatment Systems

**POWER & ENERGY ISSUES**
* Leak Detection for USTs
* Leak Treatment for USTs
* Leak Detection for Utility Pipelines
* Aboveground Alternatives to USTs
* Repair of Utility Pipelines

Clean Air Act Compliance

Efficiency of Small Generators

Waste Separation-Waste to Energy Plants

**HAZARDOUS WASTE ISSUES**
Recycling and Reuse of Hazardous Waste
Worker Safety in Materials Handling
* Alternatives to Landfill Disposal
Management and Regulations
Residential Hazardous Waste
* Spills and Cleanup Technologies
* Groundwater Pollution Monitoring/Containment
Hazard Identification ofMaterials

** ASCE Civil Engineering Research Foundation Survey, 1994[4]

* Problems and Needs Related to NRMRL's Water Supply and Water Resources
Division

**SOLID WASTE ISSUES**
Management of Residential Collection
Source Reduction by Composting
Separation Technologies in Materials Recovery
Separation of Waste in Residential Collection
Source Reduction of Litter
Equipment Maintenance for Resid. Collection
Materials Recovery by Paper Recycling
Waste Management for RCRA Compliance

**TRANSPORTATION ISSUES**
Maintenance and Repair of Pavements
* Drainage of Highways and Roadways
Asphalt Performance for Pavements
Inspection & Management of Pavements
Maintenance and Repair of Bridges
Roadway Markings and Signs
* Roadway Snow Removal and De-icing
Road Crew Safety

**BUILDINGS ISSUES**
ADA Compliance
Maintenance of Building Systems

Construction/Demolition Worksite Safety
Excavation Safety
Flood Protection
Lighting Efficiency
Construction/Demo Scheduling & Estimating
HVAC & Plumbing Efficiency